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Adaptive control in optical fibers

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Abstract: Adaptive control in combination with ultrafast pulse shaping provides a compelling approach to defeat dispersion, distortion and harness nonlinear phenomena on the femtosecond timescale.

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Ultrafast pulses propagating in optical fibers generate a number of linear and nonlinear effects which affect the pulse during its travel. The main causes stem from the dependence of the index of refraction on frequency (given that short pulses have a large bandwidth) and from the so-called self-action effects which involve the dependence of the index of refraction on the pulse intensity (which is high given that the pulse energy is confined to a very short amount of time).

Adaptive control techniques use a feedback mechanism in conjunction with a pulse shaping apparatus which scans through a variety of ultrafast waveforms to optimize a certain process using as a metric for performance a suitable control variable. This concept was first introduced by Judson and Rabitz [1] and is at the basis of the very promising and scientifically rich field of coherent control.

We describe here the application of this approach with issues specific to short pulse propagation in optical fibers. As mentioned above, the physical interaction between ultrafast light and matter alters the pulse through linear and nonlinear effects changing its shape and, in the most extreme cases, destroying it. In fact, nonlinear effects are one of the principal limiting factors to the information carrying capacity of optical networks. We have explored both theoretically [2,3] and experimentally [3,4] the use of adaptive pulse shaping to control nonlinear effects in fibers. In particular, we show that both spectral amplitude and phase shaping can produce robust short pulses with minimal pulse distortions over many nonlinear propagation lengths. A NLSE-based simulation, which mimics a femtosecond adaptive control experiment, is used to investigate chirped pulse propagation employing amplitude filters which yield optimized pulse shapes even without using sophisticated filtering conditions [2,3]. The dependence on pulse energy fluctuations and multiple pulse transmission has also been addressed in this context. An experimental demonstration has also been carried out with a phase-only pulse shaper [4]. The pulses used in this case are of sufficient peak power to be operating in the nonlinear regime and to be nonlinearly distorted during propagation, and these effects are overcome by adaptive control. Through this approach we have demonstrated the propagation of femtosecond pulses over 10 m using adaptive spectral phase shaping. Further demonstration of the power of these methods for pulse propagation in optical fibers has been obtained by experimentally demonstrating the ability to control highly nonlinear phenomena such as the soliton self-frequency shift [5].

While our results were obtained using simple pulse shaping implementations, current state-of-the-art methods can substantially extend these results. Adaptive pulse shaping holds the promise to become a powerful technique in controlling ultrafast pulse propagation in fibers and in the design of short-pulse propagation schemes.

References

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